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Authors

Mahboubi, Hossein
Haidar, Yarah M
Kiumehr, Saman
et al.

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Customized Versus Noncustomized Sound Therapy for Treatment of Tinnitus: A Randomized Crossover Clinical Trial

Hossein Mahboubi, MD, MPH[1], Yarah M. Haidar, MD[1], Saman Kiumehr, MD[1], Kasra Ziai, MD[1], and Hamid R. Djalilian, MD[1,2]

Abstract

Objectives: To determine the effectiveness of a customized sound therapy and compare its effectiveness to that of masking with broadband noise.

Methods: Subjects were randomized to receive either customized sound therapy or broadband noise for 2 hours per day for 3 months and then switched to the other treatment after a washout period. The outcome variables were tinnitus loudness (scored 0-10), Tinnitus Handicap Inventory (THI), Beck Anxiety Inventory (BAI), minimum masking levels (MML), and residual inhibition (RI).

Results: Eighteen subjects completed the study. Mean age was 53 ± 11 years, and mean tinnitus duration was 118 ± 99 months. With customized sound therapy, mean loudness decreased from 6.4 ± 2.0 to 4.9 ± 1.9 (P = .001), mean THI decreased from 42.8 ± 21.6 to 31.5 ± 20.3 (P < .001), mean BAI decreased from 10.6 ± 10.9 to 8.3 ± 9.9 (P = .01), and MML decreased from 22.3 ± 11.6 dB SL to 17.2 ± 10.6 dB SL (P = .005). After 3 months of broadband noise therapy, only BAI and, to a lesser degree, MML decreased (P = .003 and .04, respectively).

Conclusions: Customized sound therapy can decrease the loudness and THI scores of tinnitus patients, and the results may be superior to broadband noise.

Keywords

tinnitus, sound therapy, customized sound therapy, clinical trial, masking, tinnitus handicap inventory, minimum masking level, residual inhibition

Introduction

Tinnitus is characterized by the perception of sound in the absence of an external stimulus. It is a common condition in both adult and pediatric populations and can result in considerable functional impairment.[1-3] In the military veteran population, tinnitus is the most prevalent service-connected disability, with over 1.1 million veterans collecting disability.[4] Intolerable and bothersome tinnitus can lead to anxiety, depression, and insomnia, which all can negatively impact an individual's quality of life.[5-7] As a result, those with tinnitus can have a poor quality of life, mental distress, and disability.[8]

Various treatment modalities have been introduced and implemented for tinnitus therapy, but the evidence regarding their effectiveness is limited. Recent clinical practice guidelines published by the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) only endorsed cognitive behavioral therapy (CBT) as a recommended modality and regarded sound therapy as an option.[9] Both CBT and sound therapies have been increasingly employed in the recent decade to reduce tinnitus loudness. The Veteran's Administration (VA) has developed a comprehensive protocol on progressive tinnitus management (PTM), which has been used in VA hospitals and clinics.[10] Sound therapy can serve as a distraction tool from

[1]Division of Neurotology and Skull Base Surgery, Department of Otolaryngology – Head and Neck Surgery, University of California, Irvine, CA, USA
[2]Department of Biomedical Engineering (HRD), University of California, Irvine, CA, USA

Corresponding Author:
Hamid R. Djalilian, MD, Director, Division of Neurotology and Skull Base Surgery, Department of Otolaryngology - Head and Neck Surgery, University of California Irvine, 19182 Jamboree Road, Otolaryngology-5386, Irvine, CA 92697, USA.
Email: hdjalili@uci.edu

tinnitus and provide a soothing sensation to the patient by masking tinnitus. Most recently, customized sound therapies have been developed to tailor the acoustic energy based on patient's tinnitus pitch and hearing. Our group has developed the harmonic sound therapy, which is a customized masking strategy specifically designed to deliver targeted acoustic energy. This sound therapy uses patients' pitch-matched frequency along with the intra-aural and inter-frequency attenuation characteristics and creates a sound file that is composed of a series of narrow-band noise peaks centered on the pitch-matched frequency and its first and fourth subharmonics. This technique would allow for reduced acoustic energy delivery while leaving a portion of the mid-frequencies unmasked.[11,12] In this study, we sought to investigate the effectiveness of the harmonic sound therapy in a clinical trial and compare its result to that of simple masking with broadband noise sound therapy.

Materials and Methods

Subject Enrollment and Pretrial Assessments

Upon approval by the Institutional Review Board at our institution, participants were enrolled in the study through our clinic and included interested subjects from our affiliated VA hospital. The inclusion criteria included age greater than or equal to 18 years of age and presence of tinnitus for at least 3 months or more. The exclusion criteria included patients with abnormalities of the ear canal, active illicit drug use or alcohol dependence, active ear infections, history of psychosis, pulsatile tinnitus, and those currently under another sound or masking therapy for tinnitus. Pretrial procedures included obtaining informed consent, obtaining pretreatment standard audiometry, and ensuring a previous consultation with an otolaryngologist to determine that there is no treatable cause of the tinnitus (eg, cerumen impaction). Data on demographics (age and gender), tinnitus characteristics, and psychoacoustic assessments were obtained.

The subjects were queried regarding their tinnitus characteristics. Tinnitus duration was recorded in months. Subjects were asked about tinnitus characteristics including the quality of the tinnitus sound (ringing/tonal, buzzing/hissing, or multiple sounds) and localization of the sounds. In addition, subjects were asked to rate their tinnitus loudness on a scale of 0 to 10 based on the visual analog scale (VAS) and complete the questionnaire for Tinnitus Handicap Inventory (THI), which were the primary outcomes measured. Additionally, the subjects were asked to complete questionnaires for the Beck Anxiety Index (BAI) and Beck Depression Index (BDI), which were used to assess anxiety and depressive levels in tinnitus patients as secondary outcome measures.

Psychoacoustic assessments were performed following a standard audiometry. These assessments included investigating subjects' tinnitus pitch, loudness, and noise match as well as minimum masking level (MML) and residual inhibition (RI). Audiometry was performed using a calibrated Grason-Stadler Audiometer (Model GSI 16, Eden Prairie, Minnesota, USA) in a double-walled soundproof room using EarTone 3A insert earphones (Audiometrics, Oceanside, California, USA). Tinnitus pitch was matched by first presenting sound stimuli at 1 kHz and asking the subjects whether their tinnitus had a higher or lower pitch. Based on their response, an octave frequency higher or lower was presented. This was continued until the pitch was narrowed down to within an octave. Inter-octave frequencies were then presented to determine a pitch match to the closest half-octave. The sound stimuli were presented to the contralateral ear. If the subject had bilateral tinnitus, then it was presented to either the better hearing ear or a random ear if the hearing status was the same. The tones were presented at 10 dB SL. The inter-octaves were also tested to yield the closest match. Once the subject chose the closest match, tones an octave higher and lower were presented again to account for possible octave confusion. Narrow band noise matching served to determine whether the tinnitus sounded more like a pure tone or narrow band noise.

Next, MML was tested. First, broadband noise hearing thresholds were obtained, and the noise was then presented binaurally in +1 dB SL steps above the threshold of the better hearing ear. This was continued until the subject stated that their tinnitus had become inaudible. Residual inhibition was measured after MML. The RI test evaluates the post-masking effects to determine if the tinnitus can be temporarily suppressed.[2,13] For testing RI, broadband noise was presented for 60 seconds at 10 dB above MML, and then the subject was asked whether there was a change in their tinnitus loudness. The responses were categorized into (1) worse, indicating tinnitus becoming louder after 60 seconds; (2) no RI, indicating no changes in tinnitus loudness; (3) partial RI, indicating a partial reduction in tinnitus loudness; and (4) complete RI, indicating not hearing their tinnitus. If the subject reported a partial or complete RI, the length of time until the tinnitus loudness reached its pretest level was recorded and reported as RI duration.

Sound Therapy Protocols

Adobe Audition version 3.0 (Adobe Systems Incorporated, San Jose, California, USA) was used to create broadband noise for the noncustomized sound therapy. Broadband noise had a spectral frequency of 1, meaning that equal proportions of all frequencies were present. The customized sound therapy was created using the Mind:Set Technologies software (available at www.beyondtinnitus.com), which has been previously described.[11,12] Pitch matching for the

Figure 1. Spectrum analysis of a sample customized sound therapy for a patient with tinnitus pitch matched at 6 kHz and high-frequency sensorineural hearing loss. More sound is targeted around 6 kHz and a narrowband sound at 3 kHz and 375 Hz.

customization process was performed within the software using pure tones for subjects with tonal/ringing tinnitus, and narrowband noise stimuli were used for non-tonal tinnitus. Those with multiple tinnitus sounds were asked to match their loudest tinnitus sound. The stimuli were presented binaurally. The software took into account the subject's tinnitus pitch-matched frequency along with the intra-aural and inter-frequency attenuation characteristics and created a sound file that was composed of a series of narrow-band noise peaks centered on the pitch-matched frequency and its first and fourth subharmonics. The width of these bands was one-half octave of the center frequency (Figure 1). The result was a file that sounded similar to broadband noise but with less acoustic energy. This sound file was then mixed with 6 hours of classical music and uploaded onto an MP3 player (Sansa Clip+ MP3 Player, SanDisk Corporation, Milpitas, California, USA) and given to the subjects along with open ear headphones AirDrives Interactive Stereo earphones (AirDrives, San Diego, California, USA). All subjects were asked to use the MP3 player to demonstrate whether they were capable of playing the sound therapy and listening to it for 2 minutes. Noncompliance was defined as failing to listen to the sound therapy files for at least 2 hours per day every day.

Study Design and Follow-up

The clinical trial was designed as a randomized crossover study with 2 arms. The first arm started with 3 months of broadband noise therapy (noncustomized), and the second arm started with customized sound therapy (Figure 2). Subjects were assigned to either arm using block randomization with each block containing 4 patients. Subjects were instructed to listen to the sound therapy for at least 2 hours per day every day for the duration of the study. They were also instructed to adjust the intensity of the sound therapies as needed to a level that would barely mask their tinnitus. After 3 months, tinnitus loudness on VAS, THI, BAI, BDI, MML, RI, and RI duration were repeated. After a 1-month washout period to reduce the possibility of carryover effect, the subjects were switched to the other arm and received the other therapy for another 3 months. At 7 months from the start of the study, the same measurements were repeated. This crossover design allowed each subject to receive both therapies and serve as their own control.

Statistical Analysis

Simple descriptive statistics were provided on demographics and tinnitus characteristics. Mean and range of values were calculated for hearing thresholds. Mean, standard deviation (SD), and median were calculated for VAS, THI, BAI, BDI, MML, and RI. The Wilcoxon signed-rank test was used to analyze the changes in these variables. The Mann-Whitney U test was used to compare the changes between customized and noncustomized sound therapies. A *P*-value of less than .05 was considered as statistical level of significance. All analyses were performed using PASW Statistics 18.0.0 (SPSS Inc, Chicago, Illinois, USA).

Results

Twenty-three subjects were enrolled in the study. Of these, 5 subjects were noncompliant with treatment or lost to follow-up. No significant differences between these subjects and those who completed the study were noted with respect to the measured independent and outcome variables. As such, 18 subjects completed the study procedures. The average age was 53 ± 11 years (range, 26-69 years). Table 1 summarizes the demographics and tinnitus characteristics of study subjects. The mean tinnitus duration was 118 ± 99 months (range, 15-312 months). The tinnitus pitch match averaged at 6958 ± 3754 Hz (range, 250-12 000 Hz).

Tables 2 and 3 present the outcome measurements at baseline and at 3 months after customized sound and broadband noise therapies. After 3 months of customized sound therapy, the mean loudness rating on VAS decreased by 23% from 6.4 ± 2.0 to 4.9 ± 1.9 (P = .001), and the mean THI scores decreased by 26% from 42.8 ± 21.6 to 31.5 ±

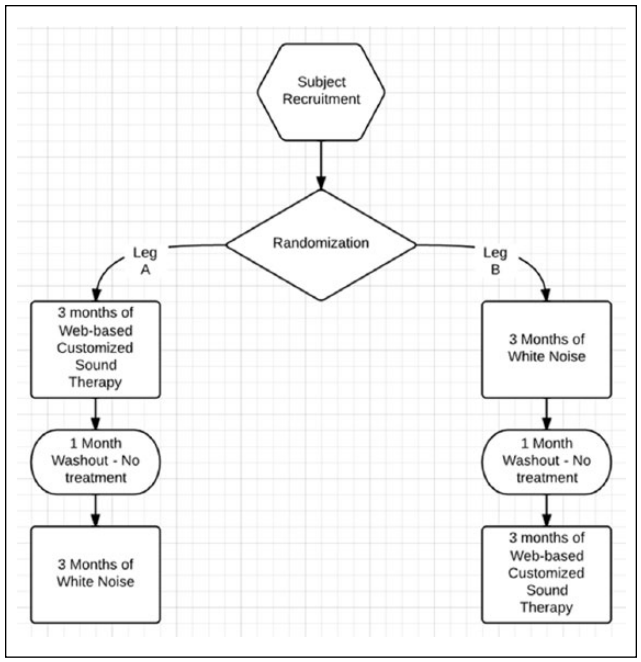

Figure 2. Randomization process of the clinical trial.

20.3 ($P < .001$). The mean BAI scores decreased by 22%, from 10.6 ± 10.9 to 8.3 ± 9.9 ($P = .01$). There was no significant statistical change in the mean BDI scores. The mean MML also decreased by 23% from 22.3 ± 11.6 to 17.2 ± 10.6 ($P = .005$). The residual inhibition type and duration did not change significantly; however, the number of subjects with complete RI increased from 1 to 4 (6%-22%).

Broadband noise therapy in the other arm of the trial only revealed significant improvements in two of the outcome measurements (Table 3). The mean BAI scores decreased by 25% from 10.6 ± 10.9 to 7.9 ± 9.8 ($P = .003$), and the mean MML decreased by 10% from 22.3 ± 11.6 to 20.0 ± 9.9 ($P = .04$). No statistically significant changes were noted in the mean loudness ratings, THI scores, BDI scores, or RI type and duration. There was no statistically significant difference in any of the primary or secondary outcomes in the groups that received either customized sound therapy or broadband noise first compared to those who received it after the crossover ($P > .05$).

Direct comparison of the 2 therapy arms revealed that the changes in tinnitus loudness and THI with the customized sound therapy were statistically greater than those of the broadband noise therapy ($P = .03$ and $P = .002$, respectively). The changes in BAI, BDI, and MML were not statistically different between the 2 therapy arms ($P = .5$, $P = .4$, and $P = .5$, respectively).

Discussion

The results from the current study revealed that the customized sound therapy protocol can improve tinnitus loudness and handicap. Tinnitus has a considerable impact and burden on the US health care and economy, and the need for a cost-effective, widely accessible, and effective treatment protocol for tinnitus has long been emphasized. While much work has been done on tinnitus epidemiology and management options, current treatment strategies have had limited or mixed success.[9] To address these concerns, a web-based software for delivery of customized sound and music therapy for tinnitus rehabilitation was previously developed by our group.[11,12] The teleaudiological approach of the customized sound therapy enables delivery of sound therapy files via the Internet, which would provide ease of access for patients. The customized sound therapy protocol used here was previously shown to be effective in web-based tinnitus pitch matching and reducing the loudness and annoyance of

Table 1. Demographics and Tinnitus Characteristics of Study Subjects (n = 18).

Demographics and Characteristics	Frequency (%)
Gender	
Male	12 (67)
Female	6 (33)
Tinnitus onset	
Sudden (<1 wk)	3 (17)
Rapid (<1 mo)	3 (17)
Gradual (>1 mo)	12 (66)
Cannot recall	0 (0)
Onset-related factors	
Long-duration noise	5 (28)
Brief nonexplosive noise	3 (17)
Ear infection/inflammation	2 (11)
Explosion (fireworks, gunfire, etc)	1 (6)
Drugs, medication	0 (0)
Stress	1 (6)
Cannot recall	6 (33)
Tinnitus frequency in a week	
Everyday	17 (94)
Most days (>3 d/wk)	1 (6)
Tinnitus frequency in a day	
Sometimes (<50% of the day)	1 (6)
Most of time (>50% of the day)	2 (11)
Whole day	15 (83)
Number of tinnitus sounds	
Ringing/tonal	8 (44)
Buzzing/hissing	6 (33)
Multiple sounds	4 (22)
Tinnitus noise-match	
Tonal	12 (66)
Narrowband noise	3 (17)
Broadband noise	3 (17)
Localization	
Both ears equal	5 (28)
Both ears, left louder	5 (28)
Both ears, right louder	2 (11)
Left ear only	5 (28)

Table 2. Outcome Measurements at Baseline and at 3 Months After Customized Sound Therapy (n = 18).

	Pretreatment Mean ± SD (Median) or No. (%)	3 Months Posttreatment Mean ± SD (Median) or No. (%)	Percentage of Change	*P*-Value
Loudness rating	6.4 ± 2.0 (6.3)	4.9 ± 1.9 (5.0)	−23	.001
THI	42.8 ± 21.6 (38.0)	31.5 ± 20.3 (25.0)	−26	<.001
BAI	10.6 ± 10.9 (6.5)	8.3 ± 9.9 (4.5)	−22	.01
BDI	6.7 ± 6.0 (5.0)	6.3 ± 8.6 (2.5)	−6	.28
Minimum masking level (dB SL)	22.3 ± 11.6 (22.5)	17.2 ± 10.6 (15.0)	−23	.005
Residual inhibition type				.05
Worse	1 (6)	0 (0)	−100	
No RI	10 (56)	8 (44)	−20	
Partial RI	6 (33)	6 (33)	0	
Complete RI	1 (6)	4 (22)	300	
Residual inhibition duration (seconds)	35.0 ± 11.5 (30)	43.6 ± 25.8 (45)	24	.18

Abbreviations: BAI, Beck Anxiety Index; BDI, Beck Depression Index; RI, residual inhibition; THI, Tinnitus Handicap Inventory.

Table 3. Outcome Measurements at Baseline and at 3 Months After Broadband Noise Therapy (n = 18).

	Pretreatment Mean ± SD (Median) or No. (%)	3 Months Posttreatment Mean ± SD (Median) or No. (%)	Percentage of Change	*P*-Value
Loudness rating	6.4 ± 2.0 (6.3)	6.1 ± 2.3 (5.5)	−5	.22
THI	42.8 ± 21.6 (38.0)	41.0 ± 20.4 (33.0)	−4	.25
BAI	10.6 ± 10.9 (6.5)	7.9 ± 9.8 (4.5)	−25	.003
BDI	6.7 ± 6.0 (5.0)	6.9 ± 8.3 (5.5)	−3	.69
Minimum masking level (dB SL)	22.3 ± 11.6 (22.5)	20.0 ± 9.9 (20.0)	−10	.04
Residual inhibition type				.9
Worse	1 (6)	2 (11)	100	
No RI	7 (39)	6 (33)	−14	
Partial RI	7 (39)	6 (33)	−14	
Complete RI	3 (17)	4 (22)	33	
Residual inhibition duration (seconds)	38.3 ± 14.7 (34.5)	42.3 ± 20.9 (42.0)	10	.38

Abbreviations: BAI, Beck Anxiety Index; BDI, Beck Depression Index; RI, residual inhibition; THI, Tinnitus Handicap Inventory.

tinnitus in a diverse group of subjects when used in short term (1 hour).[12] In this study, we found that longer usage of the customized sound therapy is also effective and may be superior to simple broadband noise therapy in improving loudness and THI score.

The subjects had statistically significant reductions noted in loudness rating, THI, BAI, and MML after using the customized sound therapy for 3 months. Improvements were seen after broadband noise therapy, but these were relatively limited. Although the changes in the RI types were not statistically significant, there was a nearly 4-fold increase in the number of patients with complete RI. In a clinical setting, THI can be reliably used to quantify the impact of tinnitus on the daily living. The subjects in this trial had a pretrial THI of 42.8 ± 21.6, indicating "moderate handicap."[14] After 3 months of customized sound therapy, this decreased to 31.5 ± 20.3 ($P < .001$), representing a significant reduction to "mild handicap," which would be considered barely noticeable and occasionally interfering with sleep. The anxiety levels as measured by the BAI had a statistically significant 25% reduction after broadband noise therapy and 22% reduction after the customized sound therapy. Given that studies have indicated a high prevalence of anxiety, ranging from 29% to 49%,[15,16] a reduction in anxiety symptoms with both short-term and long-term use can be extremely beneficial to target some of the more debilitating psychosomatic sequelae of tinnitus.

Broadband noise therapy for 3 months yielded a 10% decrease in the MML and a 25% decrease on the BAI, with $P = .03$ and $P = .004$, respectively. There were no statistically significant changes in the loudness rating, THI, or BDI. Thus, it is notable that broadband noise therapy, although to some degree beneficial, may be less effective in reducing psychosomatic markers, which are significant indicators of the morbidity resulting from tinnitus. In addition, listening to a sound therapy mixed with music can be more pleasant and may perhaps be better tolerated by

patients. Previous studies have introduced music therapy as an option in the treatment of both acute and chronic tinnitus.[17,18] The customized nature of the sound therapy would allow for reduced overall acoustic energy delivery in comparison to broadband noise and leave a portion of the mid-frequency sounds unmasked.

The crossover design in this study provided a powerful setting to compare the effects of the two arms of the study as each subject served as their own control. This design would minimize the variability between subjects with respect to potential confounding factors.[19] Another advantage of this design is the need for fewer subjects in comparison to parallel design trials to meet the same criteria in terms of type I and type II error risks.[20] Depending on the degree of variability between subjects, a parallel design study might necessitate 4 to 6 times as many patients to achieve the same power. Most trials of therapies for tinnitus are not randomized, and many are poorly designed and without control groups.[9] This study aimed to fill in this gap by studying sound therapy techniques in a randomized crossover fashion. This study is one of the first to directly compare a customized sound therapy to broadband noise therapy in a crossover setting.

There are a number of limitations associated with this approach to tinnitus management and this clinical trial, which need to be considered when interpreting its results. These include but are not limited to lack of improvement in the subjects' tinnitus, worsening of the tinnitus, and the inability to maintain the benefit achieved in the sound therapy. These might have partially contributed to the follow-up losses and dropouts. The stimulation may not reduce the tinnitus, which may lead to psychological distress such as anxiety or depression. Given significant reduction in the quality of life in tinnitus sufferers, administration of acoustic stimulus through headphones is a very small risk that is far outweighed by the possibility of suppressing the tinnitus. The 3-scale nature of the THI questionnaire may limit its sensitivity to perform a question by question analysis compared to 100-scale questionnaires.[19,21] However, it is a validated questionnaire that has been used in various tinnitus studies.[22,23] Another limitation of this study was the long-term nature of the study and the number of tests performed on each subject, which required a significant amount of time dedicated by the subjects and made it difficult to achieve high numbers for enrollment. The time commitment for the follow-up visits precluded 2 of the subjects to finish the study as their employment status changed during the study. Contralateral presentation of sound stimuli for audiometric pitch matching was used as a part of the psychoacoustic assessments of the subject. This technique may occasionally yield different pitch matches between the ear due to binaural diplacusis.[24] However, the software used binaural presentation for pitch matching to create the sound files. The randomization of the starting arm and the washout period were considered to account for any possible carrying effect from one treatment to the other. Overall, the randomized and crossover design of this clinical trial provided a unique opportunity to evaluate the long-term outcomes of customized sound therapy and compare them to those of noncustomized therapy.

Conclusions

Customized sound therapy using the tested harmonic customized sound therapy is an effective tool in the management of tinnitus, and its effects may be superior to those of the broadband noise therapy. Customized sound therapy led to a decrease in mean loudness, THI, BAI, and MML. Broadband noise therapy only decreased the BAI and to a mild degree the MML.

Declaration of Conflicting Interests

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